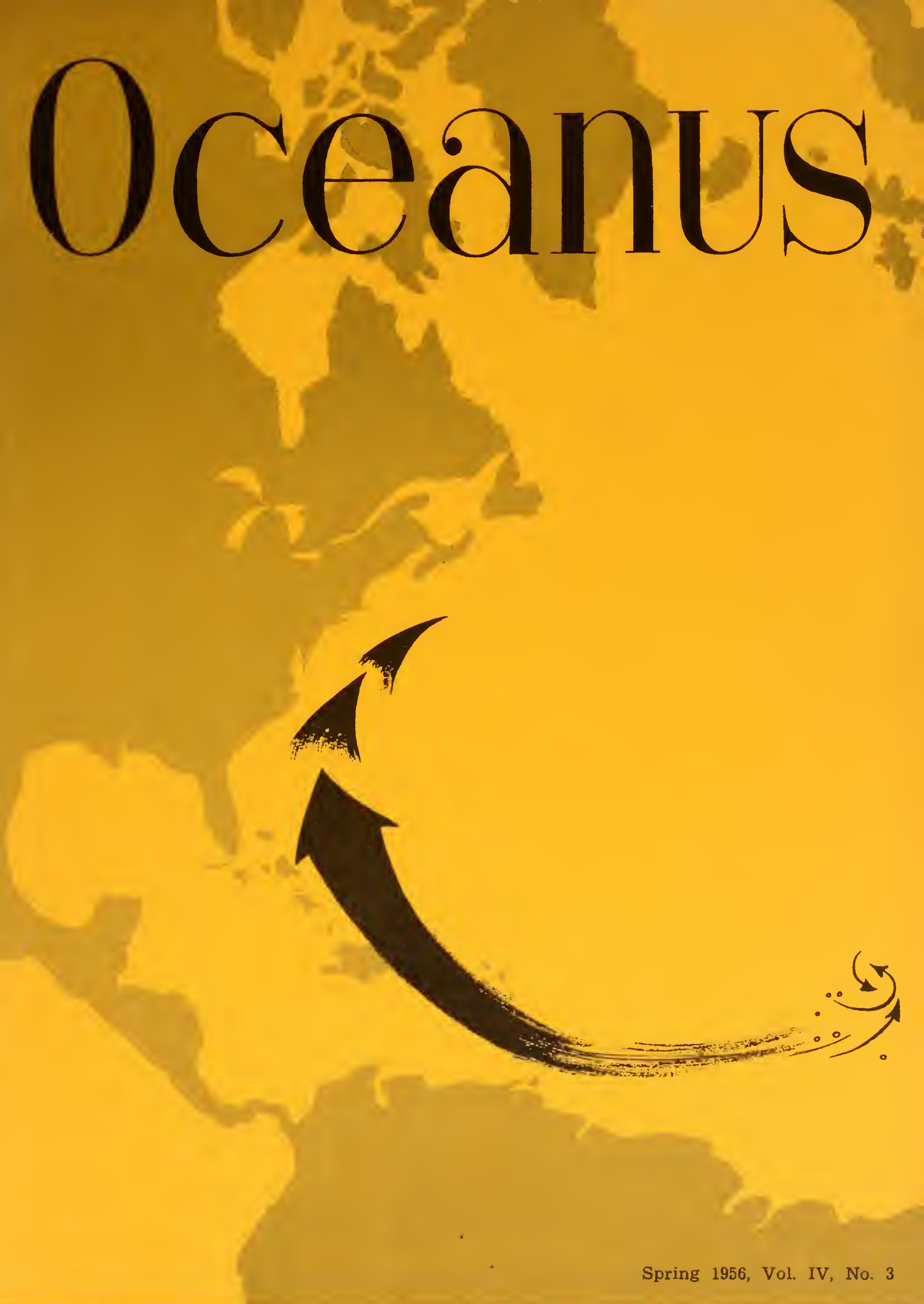
Oceanus



Spring 1956, Vol. IV, No. 3

WOODS HOLE OCEANOGRAPHIC INSTITUTION WOODS HOLE, MASSACHUSETTS

OCEANUS

EDITOR: JAN HAHN

Published quarterly and distributed to the Associates of the Woods Hole Oceanographic Institution and others interested in Oceanography

Meteorological Issue

On the cover: Our artist's conception of a North Atlantic hurricane's generating area and its path of destruction.

EDITORIAL

Spring 1956, Vol. IV, No. 3

IN this issue our contributors are not only "talking about the weather" but also explain how something may be done about it.

In a recent letter to a Boston newspaper a correspondent accused "scientists in general" of tampering with the weather, thereby causing heavy floods, snowstorms and general misery suffered by him this winter. As you will notice from the following articles, there still remain a few things to be learned before anyone can "tamper" with the weather and we certainly expect that if this day ever comes such tampering will be of general benefit. How this will be possible remains to be seen. One man's joy in rain is another man's spoiled holiday. One man's joy in sunshine is another's ruined vegetable patch. The person who will finally have to make the decisions will be in an unenviable position.

Simplified view of the general horizontal and vertical circulation in the atmosphere. Cumulus clouds forming in the Trade Wind cell. See article on page 8.

Educational Opportunities

To acquaint faculties and students interested in oceanography with the facilities at Woods Hole, the 1956 Annual Announcement was distributed recently to several hundred educational institutions. A copy was also sent to each Associate, individual and corporation, that they may be advised of the Institution's educational program. The Announcement also explains the opportunities open to undergraduate and graduate students to do research at the Institution and explains the Fellowships and Grants awarded each year.

The Woods Hole Oceanographic Institution has been officially recognized as an institution of higher education by a recent ruling of the Office of Education of the United States Department of Health, Education, and Welfare.

Tuna Tagging

Dart type tags, harpoons and instructions are ready for distribution for this year's cooperative tagging program. The equipment is available free of charge and it is our hope that the sport fishermen among our readers will encourage their friends and clubs to make this an outstanding tagging season.

News from the Pacific gives us hope that we may also obtain some returns this year. One of only 82 big-eye tuna, tagged by ships of the Pacific Oceanic Fisheries Investigations 400 miles northeast of Midway Island, was caught again ten months later 690 miles north of Oahu Island in the Hawaiian Group. The tuna had travelled 800 miles and grown ten pounds.

Life Membership

The Executive Committee of the Associates of the Woods Hole Oceanographic Institution has recommended, and the Trustees have authorized, the establishment of Life Membership to those interested in the study of the ocean and wishing to further the scientific and educational aims of the Institution. This membership has been placed at $1,000.00

We are most pleased to report as the first Life Member:

Mr. Harry Alfandre
Montauk Point, L. I.

We Hope To Witness The Start Of A Hurricane

by C. O'D. Iselin

Basic atmospheric and oceanic information will be gathered by our new ship.

THE cumulus cloud is the work horse of tropical meteorology. It is the vital and critical link in the transfer of heat and water vapor from the sea surface to the atmosphere. Huge areas of the tropics are covered by cumulus clouds which are often arranged in long bands separated by areas of less dense cloud cover. The life cycle of an individual cumulus cloud is usually less than half an hour, but few people have the patience to watch one for long, especially when thousands of them are in sight. Since the Wyman-Woodcock expedition of 1945 in a Navy PBY plane, several members of our staff have continued to be interested in the dynamics and physical chemistry of warm cumulus clouds, the characteristic cloud of the marine tropics, an area which covers about 40% of the earth's surface.

Anyone reading "Tropical Meteorology" by Herbert Riehl, the newest and most complete discussion of the warm end of the great atmospheric heat engine, is struck by the many significant contributions of our staff. Dr. Joanne Malkus has continued and developed the pioneer studies of Mr. Henry Stommel on the dynamics of large scale convection in and beneath clouds. Mr. Andrew Bunker has made most of the measurements of turbulence both within the clouds and in the clear areas surrounding them. Mr. Alfred Woodcock is our expert on the role of giant condensation nuclei in the initiation of rain. Mr. Duncan Blanchard has assisted him in studies of the details of the formation of sea-salt nuclei and recently has begun a study of the associated electrical phenomena present near the sea surface and within the clouds. Mr. Theodore Spencer has produced most of the instruments to observe these phenomena.

The expeditions gathering the basic atmospheric information have for various reasons mostly taken place during the winter season. This is also true of the cruises of our ships. Thus we have gained a relatively clear winter picture, both of the oceanography of the surface layer of the tropical North Atlantic, including the Caribbean Sea, and of the physical characteristics of the lower layer of the winter atmosphere. In the tropics this is the orderly season. Although many variable phenomena are at work, the system as a whole is in balance. The winds blow steadily from the east. The sky is covered rather uniformly with relatively small clouds. While showers occur, especially during the afternoon, a disturbance as violent as a small thunderstorm is rare until the equator is approached. Storms are nonexistent. In winter, then, small scale, convective processes over the tropical Atlantic are rather orderly and uniformly distributed. No large scale, organized convective phenomena, such as a hurricane, appears.

For obvious reasons, last autumn we began to think about the oceanography and meteorology leading up to the formation of a hurricane. Between us, we soon evolved a plausible physical model of the birth of a hurricane, but we found that we had practically no data that could be used to support or to refute this model. We had kept our ships out of the tropics during the summer season and so have nearly all other oceanographers. Our data on tropical clouds are similarly limited. Since hurricanes form along a rather narrow band of the marine tropics, centering 5° to 8° away from the equator, perhaps oceanographers could make a significant contribution to their understanding, for they are a uniquely marine phenomena.

New vessel.

A general plan of attack rather quickly evolved, but we had no really suitable ship. One reason that we had not sent the "Atlantis" south during the summer is that in so small a steel ship the heat and humidity below decks are almost unbearable. Another is that she is somewhat slow to be dodging even newly formed hurricanes. However, in October we received word that the U. S. Coast Guard had decided that three of its 125′ cutters could be disposed of. The Director vigorously followed up this lead and, after plowing through a mountain of red tape, by January we were the proud owners of an excellent vessel whose engines had only been used during three, ice free seasons in the Great Lakes. The "Crawford" is now at Munro's Shipyard in East Boston being converted for scientific work. It is hoped that by early June she will be ready for sea and it is planned that her first five months as a research vessel will be devoted to hurricane research. Some initial financial support has been promised by the U.S. Weather Bureau and it is hoped that more will follow.

Although a departure from our main theme, a brief discussion of the conversion of the "Crawford" may be of interest to the sailors among our readers. In January the Executive Committee authorized the expenditure of $100,000 for this conversion and the firm of M. Rosenblatt and Son was asked to undertake a feasibility study of some rather novel ideas which might make the "Crawford" a really superior research vessel. For some time the design of the "ideal" oceanographic vessel has been under discussion and preliminary study. Within the Navy a preliminary design has been prepared. This is for a vessel of 1000 tons displacement and the gross weight of the "Crawford" is less than one third of this. Nevertheless, it seemed possible that two of the chief features of the Navy's proposed design might be incorporated into the "Crawford" namely both passive and active anti-rolling tanks, and a bow jet pump propulsion unit for holding the vessel head to the seas without forward motion so as to facilitate lowering instruments to great depths.

Our naval architects have recommended against these particular features in a vessel so small as the "Crawford". Anti-rolling tanks would take up too much of the space necessary for living quarters and instead they have advised in favor of an active rudder, a German development which is installed on their newest research vessel. Fortunately other more important features of the conversion could be achieved within the limits of displacement and funds available. The endurance of the 'Crawford" is being increased to 30 days and 6000 miles. Her living quarters are being re-arranged and air conditioned, and a large deck laboratory is being added. Although we will still have to put up with a certain amount of roll while on station, in all other respects she should make an economical and comfortable vessel for prolonged field work in the tropics.

Birth of a Hurricane.

What is this physical mode of the birth of a hurricane that we plan to test out with the "Crawford" during the next several summers? First of all, it is supposed that the situation becomes particularly ripe for the formation of a hurricane after a period of abnormally light winds across the northern half of the trade wind belt. Light winds in theory result in several important effects. As far as the sea is concerned, heat accumulates near the surface. So far as is known, hurricanes only form in areas where the sea surface temperatures are higher than 27°C. Light winds, according to Mr. Woodcock's studies would also result in the production of too few of the larger condensation

The Crawford at Woods Hole, now being converted to a research vessel, will start soon on the first cruise ever made by a scientific ship to study the birth of a hurricane.

nuclei and consequently few of the lower clouds would rain out. Thus the humidity of the lower layer of the atmosphere can build up to abnormal levels. A large supply of especially warm and humid air over the sea is the first requirement of a hurricane, for this becomes an unstable situation. Our model goes on to suppose that at this point a large scale wave-like disturbance occurs in the light easterly winds. As this wave travels westward, locally at its crest the winds pick up so that white caps are present. A supply of larger condensation nuclei is then available to the low level convective processes. Clouds can begin to rain out and the energy of latent heat accelerates the convection. Locally the surface winds further increase, bringing more moist air and a really adequate supply of salt particles to the region of most active convection. The clouds increase in height and remain active for a long time so that the low level wind flow becomes organized over a considerable area, as when the whirl forms over the drain in a wash basin. From there on the disturbance can be clearly recognized as a hurricane. Its duration and intensity will depend only on the quantity and moisture content of the warm, low level air available to it.

Prevent hurricanes?

There is nothing radically novel about this model and so far as it is known it fits the facts. What is exciting is that if the picture presented here is found to be basically true. it is conceivable that the formation of hurricanes could be prevented. What is necessary is to maintain random convective activity during the build up period, to bleed off energy at scattered points before any large scale pattern of flow can become organized. Mr. Woodcock's studies suggest several techniques by which this might be accomplished. It is too early to attempt accessing the engineering problems involved. If we are lucky, perhaps the "Crawford" will return in September with the necessary data. In any case, it seems quite possible that if detailed studies at sea can be continued during several seasons, a weak link in the chain of events can be found. What makes the difference between hurricanes and no hurricanes is clearly something quite subtle. It is believed that hurricanes start as weak disturbances. This is the time for man to try to attack them. By the time they become recognized on the weather maps the energy has become organized and it is too late. At any rate, we mean to have a good try.

Observations.

To study at first hand the details of the environment in which they form will be a new approach to hurricane research. Meteorologists work from weather maps, which are particularly deficient in reliable observations from mid-ocean areas in the tropics. To attack the observational part of the problem with aeroplanes, as a well organized Weather Bureau team will be doing simultaneously, may leave a critical question unanswered. If our model of the situation is correct, it is vital to be able to measure small changes in surface wind velocity. Low level winds are extremely difficult to observe accurately from a plane. Thus we believe that the "Crawford" may provide the key information that will bring success to the very major research effort that was triggered off by the North Atlantic hurricanes of the past two seasons. Once full understanding has been gained, the question of whether or not weather modification at sea will become practical depends mainly on how weak the weak link in the chain of events turns out to be.

Columbus O'D. Iselin,

Oceanographer, was director of this Institution from 1940 to 1950. He started his career as a Harvard student by making a survey of the Labrador Current with his schooner "CHANCE." Now teaching a half course in oceanography at Harvard University he also serves as advisor and consultant to many government departments. He is a member of the National Academy of Sciences and received an Honorary Doctorate from Brown University in 1947.

Trade Winds and Trade Wind Clouds

BY JOANNE S. MALKUS

Trade Wind Clouds form a link in providing the energy for all the wind systems of the globe.

THE visitor to the islands in the tropics is struck by two outstanding features of the weather: The first is the regularity and monotony of the east wind, which even at night does not stop from rattling the palm leaves. The second is the beautiful and exotic array of clouds.

The trade winds, covering about 40% of the earth's surface, are the world's most extensive and most steady wind system. For comparison, the middle latitude westerlies with whose variability we are well acquainted cover about 30% to 35% of the earth's surface.

Meteorologically, the trade winds and the trade cumuli are most important. Trade cumuli are not just a feature of sunny days, as are their relatives in our temperate latitudes, but appear around the clock, and are as much visible in full moonlight as in the baking noonday sun. Even in the turbulent gray cauldron of a tropical storm the trade cumuli are found below the overcast, made ragged by the high winds, but still with patches of sea visible between them. The tropical storm, however, though spectacular and in its intense versions hideously destructive, is a rare phenomenon, much less common than the larger frontal storm of middle latitudes. Trade-wind weather is far more faithfully characterized by the first illustration than by the last, and its outstanding feature is sultry monotony.

Because of the rarity of storms, rainfall in the trade-wind region, in latitudes 10°-30° North and South, is unreliable. Most tropical islands are water-starved communities. Even the casual visitor to the Virgin Islands, for example, is impressed by the large concrete catch-basins scarring the hills, and the strict economy of water use by the local inhabitants. Study of the life cycle of the trade cumulus is thus of economic importance. It is of practical value to discover what causes these clouds to form and develop, how small cloud droplets grow into much larger raindrops within them, and in particular why some clouds grow to enormous proportions and others are cut off after a few hundred feet.

Woods Hole Studies

The meteorology group of the Woods Hole Oceanographic Institution has been involved in the study of these clouds since the close of World War II. Theoretical and experimental work on cloud and precipitation growth has been carried out at the Woods Hole Laboratory and frequent field trips to the Caribbean area have been made. During the field trips a meteorologically-instrumented PBY aircraft, loaned to the Institution by the U. S. Navy, has been flown into clouds of assorted sizes, and cross sections of their temperatures, humidities, and draft structure were drawn.

In comparing these detailed studies of individual clouds with larger-scale investigations of the circulations and features of low-latitude meteorology as a whole, some surprising and important connections have been brought to light. It now appears as if the humble trade winds clouds form a vital link in the mechanism driving the trade-wind circulation and thus in providing the energy for all the wind systems of the globe.

> Dr. Malkus well known in meteorological circles, recently returned from England where she spent a year as Honorary Lecturer in the Meteorological Department of the Imperial College. She has made frequent flights on board the PBY amphibious plane which we have on loan from the U.S. Navy.

To understand this, it is necessary to give a brief description of low-latitude air motions.* The atmospheric circulation from latitudes 0° to 30° on either side of the equator consists fundamentally of a meridional cell, with rising motion over the heated equatorial doldrums and sinking motion in the subtropical high pressure belt which circles the globe at about latitude 30°. The division between vertical ascent and descent lies about halfway between these bounds, or around 15°. The motion near the surface of the earth is thus equatorward at low levels and poleward higher up. Because of the earth's rotation, the low-level equatorward-moving air is deflected to its own right (looking downwind) in the northern hemisphere and to its left in the southern. This combination of effects produces the "trades," northeasterly winds in latitudes 10° - 30° North and south easterly winds in correspond-

Irregular clusters of Trade Cumulus clouds are commonly found over the sea, separated by slightly larger clear areas.

Definite lines of clouds are sometimes formed, generally, though not always, parallel to the wind.

ing south latitudes. At higher elevations the easterlies weaken, and are overlaid by westerlies in some areas. As mentioned earlier, the low-level easterlies are a remarkably steady wind system, far more constant than any winds of the temperate zone. This fact is brought home forcibly to the visitor to the tropics when he sees the airports there — which are built with only one runway, facing east-west.

Heat engine

Now it turns out, as a result of recent researches, that trade winds and their maintenance are intimately related to the presence and activity of the clouds. To explain this we may regard the tropical circulation cell just described as a large, and very inefficient, heat engine which exhibits many of the properties of a man-made servomechanism. To carry the analogy a bit further, the clouds may be conceived as the fuel pump for the engine, in that they carry up heat from the warm tropical seas and distribute it through a vertical depth of air so that it may be used in maintaining the pressure gradients which drive the easterlies against friction. The servo-control comes in because the clouds are forever operating against resistances or brakes. It so happens that if the clouds are weakened, the overall air currents change in just such a way as to release these brakes slightly and clouds are permitted to surge forth with renewed vigor restoring the heating and thereby the air currents to their original condition. Thus there appears to be a "stable coupling" between the small-scale phenomena, namely the clouds, and the much larger-scale air currents, namely the easterly trades themselves. It is an interesting confirmation of these ideas (which have recently been worked out quantitatively) that above the height reached by the cloud tops, or about 10,000 ft., the steadiness of the flow vanishes, and the upper level

In the turbulent gray cauldron of a tropical storm the cumuli, made ragged by the high winds, are still found below the overcast.

Small cotton puffs in the foreground stand out in contrast with the giant towers in the background, reaching an elevation of 50,000 feet.

winds of the tropics are as variable as those of our own latitudes.

Hurricanes and Brakes

Of course, we know that the servomechanism sometimes gets out of control in localized regions. Especially in the more westerly portions of the trade-wind oceans the fuel pumps occasionally work too energetically over a small area and the earth's rotation helps convert some of the energy released by precipitating clouds into a wave-like disturbance, or in severe cases into a whirling hurricane vortex. Devastating though these may be to man and his artifacts, the atmosphere recognizes tropical storms only as rare and insignificant backfires which contribute negligibly to the energy conversions normally going on in a smoothly operating engine. Ordinarily the brakes against convection are working so effectively that most potential storms in the tropics perish in anonymous infancy.

It is thus of importance for multifold reasons to learn more of the "brakes" or resistances operating against cumulus cloud development. It now appears that these resistances are not only inhibitors of precipitation and storm growth, but play a regulatory role upon the rate at which energy is fed into the large-scale circulations. Much of the work of the Woods Hole meteorology group has therefore been focused upon this aspect of the problem. It has been learned that these resistances are primarily of three kinds:

(1) Sinking motion in the environment, which changes the air structure so that the clouds are prevented from forming.

(2) A force analogous to aerodynamic drag which reduces the momentum of a rising lump of buoyant air or cloud tower.

(3) Turbulent mixing of the cloudy air with the drier environment. This eats away the cloud's energy supply, which has been found to be the heat re-

leased by condensation of water vapor into liquid water.

Using these concepts it has been found possible to construct a theory of a cloud near the middle or well-developed stage of its life history. This model has compared well with the cloud cross-sections obtained by the PBY aircraft. Recently, preliminary efforts have been made to construct the theory of the origin of a cumulus and to learn how a lump of warm buoyant air organizes its motions in the early stages. Laboratory and further field studies are being carried out to check and guide the theory. Simultaneously, investigations of the raindrop-forming and growth process are being continued at Woods Hole. It is believed that such studies must precede, and fundamentally underlie, any possible efforts to understand, predict, or control the behavior of rainfall, tropical storms, or larger-scale circulations in the trades.

ASSOCIATES NEWS

Annual New York Dinner

President Raymond Stevens, in a letter to your President McLean, stated that: "The showing of **The Silent World** was in my opinion one of the best things that has happened to the Woods Hole Oceanographic Institution in a long time. I am sure that everyone interested in the Institution is grateful."

Mid-Winter Lectures

Through your sponsorship we have had this winter at Woods Hole the extreme pleasure of listening to eight noted Harvard and M.I.T. savants speaking on their respective interests which ranged from galaxies to organic evolution and from anthropology to the science of human behavior. Capacity audiences listened every Friday afternoon to the lecturers whose attendance was obtained through the co-operation of our Trustee, Dr. Harlow Shapley.

Associates Fellowships

Announcements of two Associate Fellowships for 1956-57 went out early this year to attract two college graduates. It will be remembered that Mr. Roderic B. Park now at the California Institute of Technology was appointed last year, and that a total of three Fellowships are to be awarded each year. Successful candidates will be reappointed for the normal three-year period of graduate education leading to a doctorate.

In Memoriam

With deep regret we learned of the death in January of Associate Mr. Charles W. Brown, Jr. Mr. Brown was an ardent participant in our game fish studies. Together with his son and guests on board the sportfisherman KETCHUM III, he tagged and released many tuna during the summer of 1955.

New Corporate Associates

American Export Lines, Inc.	New York, N. Y.
Esso Shipping Company	New York, N. Y.
Marine Office of America	New York, N. Y.
Newport News Shipbuilding Company Foundation	Newport News, Va.

Weather and Insurance

BY THOMAS F. MALONE

More scientific research offers hope of reducing hurricane losses to owners and insurance companies.

ONE of the primary functions of an insurance company is to protect the values which make our domestic and economic life sound and secure. Among the many factors affecting those values are health and longevity, fires, accidents — and weather. Notable progress has been made in studying and improving health conditions and extending life expectancy, and in analyzing and minimizing fires and accidents. Increasing attention is now being given to the weather factor. There are two reasons for this: the increasing complexity of our civilization which makes it more susceptible to the vicissitudes of weather, and the expansion of the protection principle of insurance to take care of losses occasioned by weather occurences in which this principle is applicable. It follows that the insurance industry has a rather vital stake in meteorology. It is of some interest to examine some aspects of the meteorological problem in which insurance is involved.

Better predictions

The most obvious instances, and certainly the most dramatic, are the major weather catastrophes, the hurricane and the tornado. Losses from these two weather phenomena mount to millions of dollars each year. Although there are not at hand, now or in the foreseeable future, means to eliminate these losses completely, more precise predictions would be of inestimable aid in reducing these losses. Improvements in prediction techniques and warning systems made in recent years have already reduced the intensity and frequency of such losses. Similar arguments apply to the more frequent but less spectacular weather occurrences. In this sense, the insurance industry has a vital interest in the prediction problem in meteorology, in more precise predictions of wind, rain, hail, tidal height, temperature, and so forth. A word of caution is in order here, in the interpretation of the term "more precise." Absolute precision in weather prediction may well turn out to be incompatible with the fundamental nature of the meteorological problem. It is likely that, as pointed out by a distinguished English meteorologist* in a presidential address before the Royal Meteorological Society: "Our answers must always be expressed as probabilities."

Whatever form improved short-range predictions may take in the future, they will be of direct and immediate interest to the insurance industry. In a broader sense, the probabilistic nature of the meteorological problem is inextricably linked to the interest of insurance people in weather matters. It is precisely because it is not possible to anticipate weather occurrences weeks, months, and years in advance that insurance is desirable covering losses due to weather. However, such insurance, if it is soundly conceived, must be underwritten with some awareness of the **probability** that a given weather event will occur. Here, the interest of the insurance industry veers from what has already been referred to as the prediction problem and focuses on the climatic aspects. In a sense, the shift in interests

*Sir Graham Sutton, April 28, 1954.

involves only semantics, because climatic data are used to predict the future from a consideration of the past. Here, the attempt is, or should be, to determine the probability or likelihood that damaging hail will fall on a particular tract of land, that wind in excess of a critical value will cause damage to a radio or television tower or to a home or business building, that the distribution of winds in the atmosphere would distribute uncontrolled radioactive particles in a particular pattern of fall-out, or that a combination of wind and waves at sea would cause loss of life and property to shipping operations or to off-shore oil drilling and exploration work. Such knowledge is required in the setting of rates on an equitable basis so as to provide sound and continuing protection.

Climatic trends

It is apparent that more than a simple knowledge of past climatic conditions is required. Interrelationships between climatic elements and the interaction between the atmosphere and its boundary, both land and ocean, must be known and appreciated. Moreover, cognizance must be taken of long-term (i.e., of the order or decades and centuries) climatic trends whenever they can be shown to be real and of significance. Estimates of unusual or extreme values must frequently be made from distributions which leave something to be desired in the way of completeness. Critical values of weather elements must be determined, either empirically or theoretically, From a correlation of comparatively short period of insurance experience and weather data it is frequently possible to extrapolate the insurance experience over a longer time and thus provide a broader base for underwriting. Finally, the most sophisticated treatment of climatic data may be of no avail unless it is possible to apply it in actual practice according to acceptable standards for sound insurance procedures.

In summary, the insurance industry is interested in the climatic aspects of meteorology in order to arrive at a procedure of underwriting which will permit extending the protective features of insurance on a realistic and sustained basis. It is interested in the prediction problem insofar as this can be utilized in an effective manner to minimize the losses to the insurer and hence the costs to the insured. To meet the challenge suggested by these dual interests, meteorology and its sister field of oceanography have much to offer and a great deal yet to do.

Dr. Malone is Director of the Travelers Weather Research Center, The Travelers Insurance Co., Hartford, Conn. He has had a distinguished career in the field of meteorology and is a partner of Weather Training Supplies, furnishing educational material to schools and universities.

THE Associates of the Woods Hole Oceanographic Institution, by sponsoring the distinguished lectureship series for the past three summers at Woods Hole, have contributed significantly to the educational opportunities for the staff and students at the Institution.

Announcements will soon be distributed to colleges and universities that the Associates' lecturer for 1956 at Woods Hole will be Professor B. Kullenberg, Associate Professor of Oceanography of the University of Goteborg, Sweden. Dr. Kullenberg also will be available as a consultant, and may participate in some phases of the Institution's research.

Einar Borge Kullenberg was born May 11, 1906, at Uppokra, Sweden and educated at the University of Lund taking his B.A. in 1928 and his Ph.D. in 1938. He is married and has two children. Dr. Kullenberg's professional career includes four years as a demonstrater at the Institute of Experimental Physics, University of Lund; thirteen years on the staff of the Swedish Hydrographical Biological Commission at Stockholm, and since 1939 has been a member of the staff at the Oceanographic Institute at Goteborg. In 1942 he was appointed Lecturer in Oceanography on the faculty of the University of Goteborg, and in 1948 an Associate Professor.

Dr. Kullenberg's activities include membership in Sweden's delegation to the International Council for the Exploration of the Sea, member of Goteborg's Academy of Arts and Sciences, and of the Royal Swedish Academy of Sciences. His scientific publications include articles on inertial currents in the sea, internal waves, water exchanges of harbor and channels, marine sediments, and the techniques of core sampling. The Kullenberg piston corer, for which he is probably best known, was used effectively on the round-the-world Swedish Deep-Sea Expedition of 1947-48, when cores of sediment as long as

66 feet were obtained. He has unusual ingenuity in the design of oceanographic instruments.

Dr. Kullenberg is a cultured scholar of social poise and gifted as a raconteur. He likes chess and often plays it blind. The summer of 1954, he was one of the eminent scientists attending the dedication ceremonies of the Laboratory of Oceanography at Woods Hole where again he will find many friends and admirers waiting to extend to him a warm welcome.

E. H. S.

Research in marine meteorology at the Institution is supported by contracts with the Office of Naval Research, U.S. Navy, the U.S. Weather Bureau, and the support of basic research by the associates.

BUBBLES SALTDUST and RAINDROPS

BY A. H. WOODCOCK

Salt particles from the sea play a role in rain formation.

EVERYONE knows that winds blowing over the sea carry water vapor from the ocean areas to the land areas of the earth, and that this water vapor eventually falls as rain or snow. But, it is less well-known that these winds also transport an average of about 30 pounds of sea salts per cubic mile of air, and that this salt seems to be important if not essential in rain formation.

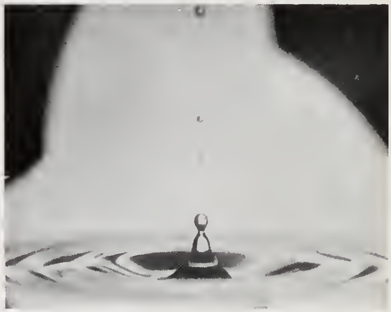
On a clear, dark night the visible "dust beam" from a flashlight reveals the presence of this salt as minute particles, shining star-like as they are tumbled about in marine air-streams. Spider webs are often strung with tiny salt crystals, some of which are just large enough to be seen with a good hand lens. On still nights these crystals often collect water, and the morning sun will reveal a "jeweled web." The number of salt particles at cloud-base altitudes is almost equal to the number found relatively near the surface. At these higher levels, clean glass slides exposed to the air from an airplane soon become "fogged' 'with the crystals or droplets which rapidly collect on the surface. After a short flight the leading edge of the propeller tip will often taste salty when touched with the tip of the tongue.

Origin of salt.

Knowledge of the nature of these atmospheric salt nuclei and of their origin is important as an aid in the search for understanding of a great many geophysical problems, the most important of which are the problems of the formation of rain and the role of airborne salts in the cycles of geochemistry.

The breaking waves caused by winds on the open sea force much air beneath the surface in the form of small bubbles. These bubbles range in size from less than one-thousandth of an inch up to about one-tenth of an inch in diameter. With ultra-slow-motion photography we have established one way in which bubbles of this size produce droplets when they burst at the surface of the sea. Several droplets are produced by each bubble and many of them remain airborne. As the water evaporates they leave a minute crystalline residue. Thus winds passing over the sea acquire a burden of salt dust simultaneously with the addition of water vapor. Well-mixed marine air, which has passed over hundreds of miles of sea surface will commonly contain from 10 to 100 of these salt particles per cubic inch, from the sea surface up to the bases of the local cumulus clouds.

Other natural phenomena which produce great numbers of small bubbles in sea water, and hence add to the salt-nuclei population of the air, are melting snow, sleet and hail, and impinging raindrops. For instance, individual snowflake clusters release as many as 500 bubbles as they melt in the surface waters of the sea. Most of the bubbles produced in the sea in this manner are of microscopic size.



High speed photograph, made in our laboratory, of droplets produced by an air bubble bursting at a water surface.

When droplets are ejected into the air from the bursting bubbles, they commonly carry with them a strong positive charge. This charge on the droplets has been measured in this laboratory by Mr. D. C. Blanchard. His preliminary results indicate that the electrical current flow due to the transfer of charged droplets from the sea surface to the atmosphere may contribute largely to the well-known electrical interchange between the earth and the atmosphere. Hence it is possible that these charged nuclei are important in the generation of thunderstorm electricity.

Sampling salt.

Here at Woods Hole we have also developed techniques for sampling and weighing air-borne salt particles. As everyone knows, table salt (NaCl) crystals tend to become wet when the weather is humid. In fact, at a relative humidity of 80% a single small crystal will, if left exposed for a sufficient time, collect enough water from the air to completely dissolve and to form a droplet. At a given humidity and temperature the amount of water collected in this way by a mass of NaC1 is directly related to its weight, and this is also true for a particle of sea salt. This fact was utilized in weighing indirectly the minute sea-salt crystals sampled in the free air. The method has been tested by direct but more laborious chemical methods.

When a small glass slide 1 mm wide was exposed from an aircraft at a speed of 70 mph, it was found that practically all of the salt nuclei larger than about one micron or 0.00025 inches in radius, impinged upon and adhered to the glass surface. These salt particles are crystalline at a low relative humidity and become liquid droplets at high humidities. Under a microscope, measurements of the diameter of the droplets enable us to compute the volume of each, and from this volume the weights of salt in solution.

Mr. A. H. Woodcock has been with the Institution since 1931. Serving originally as ship's technician on the Atlantis his curiosity and power of observation led to new knowledge about the behavior of air over the sea. These and the studies mentioned in his article have received international attention.

Rain formation.

Samples taken from aircraft have shown that the salt particles from the sea are carried by the winds to great heights, and there seems to be a physical connection between the salt in these particles and the salt in rain water. One of the most exciting aspects of the study of atmospheric salt particles concerns the role of these particles in raindrop formation. Over a period of about five years, evidence has been slowly accumulating that each large salt particle becomes the nucleus upon which raindrops form in marine air. The evidence supporting this idea was acquired by comparing the number and weight of the salt nuclei in a volume of relatively clear air with the number of raindrops, and the weight of salt dissolved in them, in an equal volume of rainy air. These comparisons are too complex to present in detail here. However, the result implies that droplets containing each salt particle grow to raindrop size through coalescence with much more numerous and relatively non-saline cloud droplets.

Measurements of the weights of salt in oceanic air are also useful in attempting to explain world-wide occurrence of chloride in precipitation and river waters. Comparisons of the weights of chloride suspended in marine winds and the weights of chloride carried onto the continents by rains, wind impingement, etc., have suggested that all of the chlorides found in river waters may come from the sea, via the atmosphere. If, however, all of the salts found in rain waters and in the airborne particles do in fact come from the sea, how is one to explain the often observed discrepancies in the ratios of these various salts as compared to the ratios of these salts in the sea?

Further problems.

Progress in understanding is often dependent upon learning enough to be able to frame detailed questions which are realistic, and which are sufficiently limited in scope to be answered within a reasonable time and with the available facilities.

Recent studies have enabled us to frame detailed and more nearly ideal questions concerning a number of problems in cloud physics and geochemistry. The future work required to answer some of the most important of these questions should, it seems to me, involve a study of the detailed mechanics of the production of droplets by bursting bubbles of the various sizes found in the sea, and the chemistry of the droplets so produced. Special attention should be given to the affects of various surface film conditions of the sea upon the chemical make-up of the droplets. The results of this study may be of great interest to geochemists and to agriculturalists.

Other efforts, aimed at further understanding of the rain-forming role of the sea-salt nuclei, should involve tracing the physical and chemical events within and near individual cumulus clouds before, during and after the time of occurrence of rain showers.

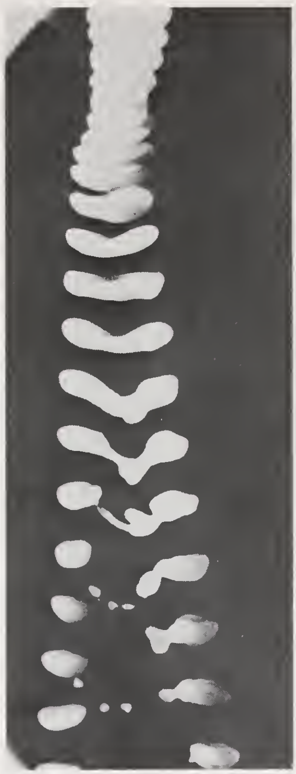
The present time is one of accelerated interest in the role of the oceans in weather processes. The outlook is for increased research effort in marine meteorology. I feel that it is important at this stage to emphasize the relatively small scale studies of the interrelationships of sea surface conditions, air-borne salts, and the conditions in and around individual cumulus clouds. These studies may provide useful evidence and understanding of the complicated sequence of events leading up to rain formation. Such understanding should be of basic aid in defining the larger problems of rain formation in the groups of clouds in marine storms such as hurricanes. Knowledge of the details of the natural rainforming process should, and probably will, lead to new ideas and methods for artificially altering this process.

The Fingerprints of a Storm

BY DUNCAN C. BLANCHARD

THE sudden downpour of a violent summer thunderstorm, the light steady rains from a grey overcast sky and the gusty wind-swept rains of the northeaster, all are familiar to us. We are quite aware of the different cloud formations, overcasts and general wind conditions that accompany these rains. But what of the rain itself? Does one ever think of differences in the nature of the rain in each of these storms?

Most of us merely classify the rain as light, medium, heavy or perhaps the well-known ultimate in intensity; cats and dogs. After all, this is a sufficient classification for most purposes. But, when we examine the raindrops themselves, there begins to emerge a rather unique feature, independent of the rate of rainfall, which may enable us to associate a particular rain with a certain type of storm. This is the size and number of raindrops present in a given space in a rain, a feature which the cloud physicists call the basic structure of the raindrop size distribution. It has been found



Laboratory photograph of raindrop disintegrating in upward moving airstream.

that a particular type of rainstorm will often have its own characteristic drop size distribution and it is beginning to appear that a storm may be typed by this distribution. This may be called the fingerprint of a storm. Existing evidence indicates that these fingerprints in oceanic rains at least, may be controlled by the minute salt particles that rise from the surface of the sea. Mr. Woodcock, in another article in this issue of Oceanus, has described how these particles originate.

Measuring drops.

The science of meteorology had existed for a long time before anyone gave thought to measuring the sizes of raindrops. The simple techniques that were used during some of the first attempts are still used today. The first measurements probably were made by the Englishman Lowe in 1892 and his observations of raindrop splashes on pieces of slate were the prelude to increased interest in the subject. A few years later Wiesner in Germany introduced a sampling technique, still widely used, which consists of allowing a small sample of rain to fall upon an ordinary chemical filter paper which has been lightly dusted with a water soluble dye. The size of the rain spots, easily visible now by virtue of the dye, can be related to the raindrop size. A novel and ingenious flour method for determing raindrop size was discovered in 1904 by a Vermont farmer named Bentley. This method consists of allowing the rain to fall into a pan containing a layer of sifted flour. The pan and contents, with the raindrops now forming soft dough pellets, are baked in a warm oven until the pellets are hard. The size of the pellets can then be related to the original raindrop size. I have used Bentley's flour pellet method and find it quite satisfactory. Indeed, a lack of cooking skill is no great handicap. It is interesting to note that Bentley was not a professional meteorologist but was engaged in these interesting scientific adventures in his spare time.

Radar echoes

The measurements of raindrop size were accelerated during and since World War II, when it was found that rain produced an excellent radar echo. Meteorologists were quick to take advantage of the opportunity offered by this new technique. Both theory and experiment proved that the reflection of a radar signal from a raindrop was proportional to the 6th power of the raindrop diameter. For example, a given raindrop would reflect a radar signal 64 times as well as a drop half its size or 729 times as well as a drop one third its size. This measure of the ability of a collection of raindrops to produce a radar echo was called the radar reflectivity or simply Z. This seemed to be the ideal meteorological tool. Higher rates of rainfall meant more and larger raindrops and consequently a much greater value of Z. After obtaining by experiment the relationship between Z and the rate of rainfall it would appear that with the aid of radar a

Duncan C. Blanchard is associated with Mr. Woodcock's meteorological group. Trained in engineering and physics, he worked with Drs Langmuir and Vincent Schaefer at General Electric Research Laboratory, Schenectady, N. Y.

meteorologist could determine how hard it was raining in a storm many miles distant.

Now, all this is based on the assumption that for a given rate of rainfall the raindrop size distribution is always the same and thus only one value of Z can exist for any given rainfall rate. But what would happen if, in two rains of the same intensity or rate of rainfall, the drops were large and scarce in the first rain and small and plentiful in the second. A little thought will show that a much greater radar echo will most likely come from the rain with the large raindrops. A single drop of 5 mm diameter produces the same echo as about 16,000 raindrops of 1 mm diameter. The differences in the raindrop size distribution that tend to confuse the estimates of the intensity of rainfall on a radar screen undoubtedly lie in the mechanism responsible for the very origin of the rain itself.

Let us look at a striking example of how two different rains, having exactly the same rate of rainfall, will give vastly different fingerprints or raindrop size distributions which apparently are a direct result of the manner in which the embryo drops are formed. During recent experiments on the island of Hawaii, A. H. Woodcock and the author obtained measurements of the raindrop size distribution in many types of rain. During one rain falling at the rate of 0.1 inch per hour we found few and big drops while in another rain we found the opposite; many, but small drops. This latter rain is typical of the rains of Hawaii, where the clouds do not penetrate to any great heights in the atmosphere and the raindrops, whose final size is somewhat dependent on the cloud thickness, are relatively small. On this basis then it is somewhat myterious to find Hawaiian rains showing sparse numbers of big drops. Is this drop distribution a reflection of some other origin of the rain, possibly entirely different from the process that produces many but small drops? This puzzling question was somewhat clarified when we looked at the weather condition that produced the few but large drops. The measurements were obtained late one evening at an elevation of about 7,000 feet on the volcano of Mauna Kea. The following morning, after the rain had ceased and clouds swept away, the entire top of Mauna Kea was covered with a blanket of snow which extended nearly down to the elevation where the raindrop samples were made.

I think we are now in a position to give a reasonable explanation of why we found the few but large drops. The raindrops evolved from snowflakes which formed high within the great cloud system that existed over Mauna Kea that night. When these rather sparsely distributed snowflakes fell down into regions above freezing they melted into small raindrops which continued to "feed" on the much smaller cloud droplets, like a large snowball growing as it plummets down a snow covered slope, until their arrival at the ground was characterized by large drops.

And so it appears that someday we may have hopes of identifying what type of rain-forming process is going on in the clouds by the size distribution of the raindrops that fall out. It will be exciting if we are definitely able to show that the distribution of raindrops in oceanic rains reflects the manner in which salt particles are produced by the sea. We will certainly have to find out how nature produces rain before we are able to duplicate the process ourselves. The problem is difficult and far from solved. We must learn more about how the drops behave in their flight from cloud to earth. The eventual answer may enable us to type or fingerprint a storm with certainty by measuring the size of raindrops.

Currents and Tides

"The effects of atomic explosions on the atmosphere and the sea" were presented to the staff by Dr. Yasua Miyake of the Meteorological Research Institute in Tokyo, who visited us in February. The essence of his talk was reported in TIME of March 20th, 1956.

Among recent distinguished visitors to the Institution were: Dr. G. E. R. Deacon, Director of the National Institute of Oceanography in Great Britain, an old friend of many staff members; Dr. G. I. Taylor of Cambridge University, pioneer into the properties of rotating fluids; and Dr. Jacques Picard, coinventor of the Bathyscaphe TRIESTE.

Honorary degrees were awarded on March 13 by the University of Oslo, Norway, to Dr. A. C. Redfield, Senior Oceanographer and to Dr. Laurence Irving, Associate in Physiology. The University of Oslo presents such awards once in five years to distinguished foreigners.

On the instigation of physical oceanographer Allyn C. Vine, the science teachers of our local High School spent an instructive evening at the Institution. Many staff members explained their respective fields, while a spirited open meeting discussed how this Institution and the staff might aid in local science education.

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